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The Influence of Lot Size on Production Performance in Wafer Fabrication Based on Simulation

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Abstract

Semiconductor manufacturing has been a significant change over the past decades. Nevertheless, from production efficiency point of view, it should be argued with validity whether 25-wafer is an adaptive lot size in the future to fulfill the manufacturing processes. In this work, a simulation model to study the relationship between lot size and the performances of wafer fabrication is proposed. Three production performance indices are taken into account in this model including cycle time of products, total throughput and the waiting time of WIP by workstation. Based on the simulation result, it reveals that the cycle time of products is synchronously decreased when the lot size is shrunk. However, the waiting time of WIP is not coincident with lot downsizing. From these results, the model of this study can provide a trend to establish the best lot size to fulfill the current and future wafer fabrication.

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Keywords: Wafer Fabrication, Lot size, Production performance, Simulation model

1. Introduction

The semiconductor industry is a high technology and capital intensive industry. Due to the characteristics of reentrant, complicated processes, time constraints issues and equipment utilization concerns, the

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production management is tougher than other industries and managers are facing many difficulties and challenges [1][2]. Besides, semiconductor manufacturing has been grown to maturity and a significant change over the past decades. For example, the wafer size is from 100mm to 300mm and 450mm in development stage; process technology migrates from 10μm above to 10 nm and the process steps is increased from several hundred steps to more than thousands of steps; the fab scale is increased to more than 100K wafer per month. Moreover, in order to improve the wafer yield, some batch process steps, such as furnace, wet bench, have been changed to mini batch or even to the single wafer process [3]. Although there are so many significant changes in wafer fabrication, the lot size still kept 25-wafer is really an issue should be addressed. Hence, from production efficiency point of view, it should be argued with validity whether 25-wafer is an adaptive lot size in the future to fulfill the more advanced and complicated manufacturing processes.

Based on JIT theory and experiences of production management in other industries, smaller transfer quantity is proved as the best policy to reduce the cycle time of product and increase the throughput [4]. However, due to the different characteristics in wafer fabrication, it is necessary to further study that the advantages of small lot size of wafer fabrication. Generally, the increasing of setup time is the most serious impact of small lot size on production performance. In wafer fabrication, there are some equipment processes which need the setup step, such as the change of mask in photolithography process, pumping down in the vacuum equipment and waiting for batching in furnace and wet bench. There will be lost on the production performance due to the small lot size. Nonetheless, as mentioned above, due to the yield concerned the batch process have been changed to mini batch or even to the single wafer process. Besides, some process limitations, such as time constraints, are getting serious in the advanced technology. Therefore, from production efficiency point of view, it should be argued with validity whether 25-wafer is an adaptive lot size in the future to fulfill the more advanced and complicated manufacturing processes.

In the study, the previous researches relevant to the determination of lot size are discussed in the section 2. The next section introduces the environment and the concepts, the analysis and discussions of simulation result is presented in section 4, and the final is conclusions.

Nomenclature

n	Number of lots in a batch
ls	Lot size (piece)
tol	Tolerance
TP	Processing time of lot which lot size equals *l*t

2. Literature review

There were many researches focused on the effects of the changes of lot size on production performance in semiconductor manufacturing. Lee [5] proposed a lot sizing decision policy to reduce the total processing time on a critical resource of wafer probe operation in semiconductor manufacturing. Wood [6] suggested that the performance improvement could be achieved by using single wafer processing and tool integration together. In addition, this study also implied that the cycle time reduction can be achieved by smaller lot size. Besides, simulation is a general tool used in the studies of lot size [7][8]. Bonnin *et al.* [9] applied DOE and dynamic simulation to review the front-end steps within a semiconductor manufacturing flow where batching requirements may be replaced by single-wafer or mini-batch alternatives for cycle time improvement.

Schmidt *et al.* [10] pointed out that a reduction in lot size transferred directly into lower raw process times. Furthermore, this research also explored the relationship between the process times and lot size of cluster tools. Wang and Wang [11] developed a simulation model which can acquire optimal lot size to reduce cycle time under different bottleneck loading environments. It also found out that a smaller optimal lot size could be applied if greater excess bottleneck utilization existed, which would result in a shorter cycle time. Schmidt and Rose [12] established a simulation to study small lot size and the replacement of batch tools with mini-batch or single wafer tools and showed that they were beneficial but lot size reduction lacks persuasive effectiveness if reduced by more than half. However, the details in the setup of related batch parameters are lacked. Zimmerhackl *et al.* [13] studied the effects of small lot manufacturing (SLM) on different machine. The result shown the small lot manufacturing can reduce 23% of cycle time. Huang [14] proposed the dedicated line for small lot size manufacturing strategy to improve cycle time. Compared with regular line, the cycle time can be improved around 21.7%. Based on the previous research, it can be found that most of the researches focused on the specific equipment to study the lot size issue. The lot size issue, nevertheless, belongs to the overall planning policy. It will get bias if the study of lot size is only based on some specific equipment. Besides, due to the advanced technology, the time constraints issues in process are getting serious. Therefore, the waiting time of WIP is concerned and should be studied as the lot size change.

3. Simulation experiment

The simulation model was constructed by using eM-Plant version 7.0 to find the relationship between lot size and production performance. The experimental environment comprises ten products manufactured separately using re-entry production flows under five process areas condition which including photolithography, thin film, implant, diffusion and etching. The fab capacity scale is set as 50K per month. The independent factor, lot size, is set from 3 pieces to 39 pieces, increasing 3 pieces per level. Hence, total 14 levels including the current lot size in fab (25 pieces per lot) are defined. Regarding the production performances, cycle time of products, total throughput and waiting time of WIP are included. The running horizon for each experiment was set at 45 days, 24 hours a day. The first 15 days was the warm-up period, and results were collected for the remaining 30 days. Each treatment was run 30 times to obtain average results.

Due to different types of production processes, the change of lot size will influence on the dispatching logic of equipment. Hence, three equipment groups are defined and their dispatching logics are introduced as follows.

3.1. Batching process equipment (M1)

Generally, the process time of batching process is fixed no matter the batch size in the process. In order to increase the rationality of production, two types of batching process equipment are defined in this study. The characters of first type are the large batch size (150 pieces) and longer process time, such as furnace. The other one is small batch size (50 pieces) and shorter process time, such as wet bench. The batching logic is different for these two kinds of batching process equipment. For large batching equipment, due to the longer processing time, the batch size cannot be greater than 150 pieces and a lot cannot be taken apart. On the contrary, for small batching equipment, a lot can be taken apart and merged when necessary. The following is the equation to calculate the number of lots in a batch. When the number of lots in a batch is not an integer, it means the last lot should be taken apart.

Large batching equipment:

$$n = [150/LS] \qquad (1)$$

Small batching equipment:

$$n = \begin{cases} \frac{50}{ls}, & when\ 50 - tol < \left\lceil \frac{50}{ls} \right\rceil \times ls \\ \left\lceil \frac{50}{ls} \right\rceil, & when\ 50 - tol \le \left\lceil \frac{50}{ls} \right\rceil \times ls \le 50 \end{cases} \quad (2)$$

3.2. Single wafer process equipment (M2)

The wafer is processed by this kind equipment piece by piece. Therefore, the change of lot size only influences on the processing time of whole lot. The processing time of lot can be calculated as the following equation.

$$PT(ls) = \frac{ls}{25} \times PT(25) \quad (3)$$

3.3. Equipment which needs setup (M3)

The setup process is needed for this kind of equipment when the different recipe is going to process, such as the change of mask in the photolithography equipment. The setup time is set as fixed time in this study. Additionally, the dispatching rule is changed to minimum setup first and then first come first serve.

The required products and equipment information are shown as Table 1 and Table 2.

Table 1. Products information

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Product ratio(%)	10	5	15	5	30	6	10	2	2	15
Process steps	123	135	162	169	176	153	166	163	168	189

Table 2. Equipment information

Machine type	Workstation	Availability (%)	MTTR (Hr.)	Average process time (Hr.)	Utilization (%)
M1	Diff_clean	98	1	0.26	77.9
M1	Furnace	92	5	6.3	90.3
M1	Wet Bench	93	2.5	0.61	84.8
M1	CVD_clean	95	1	0.21	79.4
M1	PVD_clean	95	1	0.07	90.6
M2	ADI	97	1.5	0.43	85.7
M2	Dry Etcher	92	2.5	0.94	91.7
M2	AEI	98	1	0.21	82.3
M2	IMP-Med	91	2	0.18	78.9
M2	IMP-Hi	92	1.5	0.13	87.2
M2	CVD	90	3	0.44	86.6
M2	Sputter	90	1	0.19	80.9
M3	Photo	95	2	1.19	95

4. Experimental result analysis and discussions

Based on the simulation results, they showed that the bottleneck machine is shifted to the large batching equipment and the production performances are dropped down seriously when the lot size equals 27, 33 and 39. The reason why the bias occurred is the batching logic in this system. For example, based on the batching logic, a batch processed in a furnace will be five lots when the lot size equals 27 pieces. That means the capacity will loss 15 pieces per batch. In order to eliminate the bias, the lot size level of 27, 33 and 39 are excluded in this experiment. Besides, the lot size level of 1 and 2 pieces are added in this experiment to improve the accuracy of the cycle time trend. Therefore, the lot size levels in this experiment are 1, 2, 3, 6, 9, 12, 15, 18, 21, 24, 25, 30 and 36.

4.1. Cycle times of product

From Figure 1, it reveals that the cycle times of product will decrease as the lot downsizing. However, when the lot size is less than 9 pieces, the cycle times seem to keep in stable. In order to confirm this phenomenon, statistic analyses, Duncan test and ANOVA, are applied and results are showed that lot size 1, 2, 3, 6 and 9 belong to the same group and there is no significant difference in the cycle times of product. It is to say that the optima lot size for the shortest cycle times is 9 pieces in this case. Based on this experiment, the most important point is the cycle times of product cannot decrease unlimitedly as the lot downsizing.

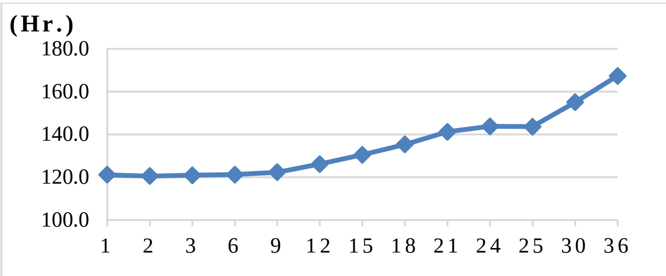

Fig. 1.The relationship between lot size and cycle times of product

4.2. Total throughput

Based on Figure 2 and the results of statistic analyses, they show that the total throughput is decreased when lot size is less than and equals 6 pieces. Although the wafer release rates are all the same, the throughputs are insufficient under these lot size levels. Moreover, they are all under target throughput. The reason is the setup times are increased on the bottleneck machine by small lot size. As mentioned above, the disadvantage of small lot size is to increase the setup times of equipment. If the bottleneck equipment needs setup process, the total throughput will be impacted. The influence level will depend on the amount of reserved capacity of bottleneck equipment.

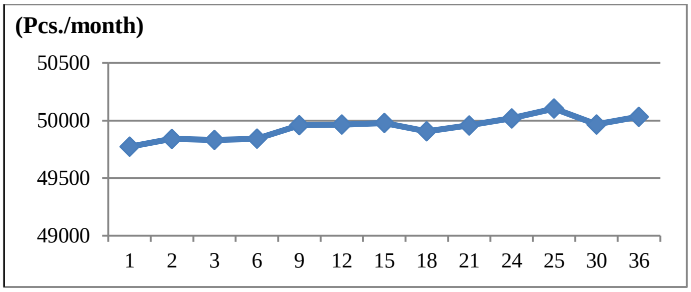

Fig. 2. The relationship between lot size and total throughput per month

4.3. Waiting time

Due to more production limitations in the advanced technology, waiting time becomes an important factor in wafer fabrication. Therefore, the waiting time should be emphasized in the changes of lot size. There are two points of view to analyze the waiting time analyses including waiting time of products and waiting time of WIP by equipment in this study.

4.3.1. Waiting time of product

Regarding to the waiting time of product, it can be found from Figure 3 that the shortest value is occurred on the lot size 25. The waiting time of product is increased as the lot downsizing or upsizing from 25 pieces. The more reasonable explanation is that the fab environment is designed for the lot size 25. For example, the batch sizes are 150 and 50 pieces for the batching process equipment. Therefore, it is beneficial for lot size 25 and it can perform well on the waiting time of product.

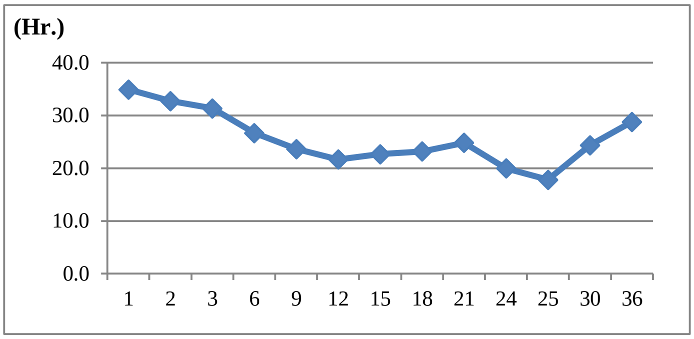

Fig. 3. The relationship between lot size and waiting time of product

4.3.2. Waiting time of WIP by equipment

As mentioned above, in order to enhance the product yield, there are many time constraints defined by equipment. Hence, the waiting time of WIP by equipment is a very important factor in the lot size policy.

4.3.2.1. Batching process equipment (M1)

Generally, the small lot size is unfavorable for batching, especially for large batching. This concept can be

verified in our experiment as Figure 4. However, from Figure 5, it shows that the influence of lot downsizing is alleviative on the waiting time for the equipment of small batching. Besides, the waiting time will also be impacted by the batching logic. For example, due to 2 pieces tolerance in batch size for the small batching equipment, the small lot size needs not to take apart. Hence, the impact on waiting time from small lot size is reduced. Because the probability of taking apart of lot is raised, the waiting time is increased on the lot size from 21 to 36 pieces.

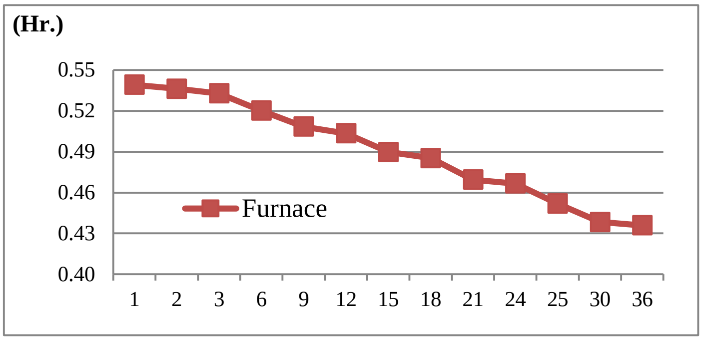

Fig. 4. The relationship between lot size and waiting time of WIP on large batching equipment

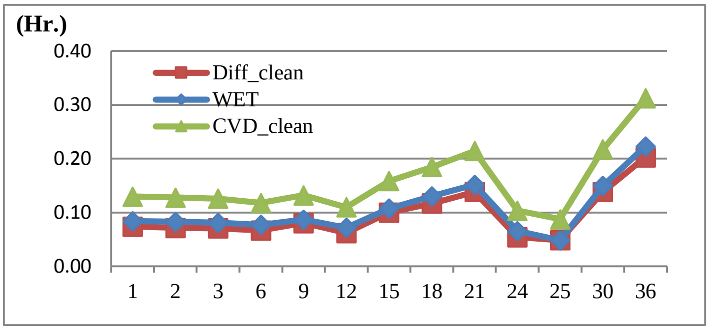

Fig. 5. The relationship between lot size and waiting time of WIP on small batching equipment

4.3.2.2. Single wafer process equipment (M2)

The processing time of single wafer process equipment (M2) will be influenced by lot size significantly. From this experiment, it shows that the waiting time of M2 is also influenced by lot size. In addition, the upstream processing equipment and the average processing time of single wafer are all the major factors to influence the waiting time of M2. Hence, based on the type of upstream equipment and the processing time, three groups are defined to discuss the changes of waiting time by lot size.

- Upstream equipment belongs to M2 and the average processing time of single wafer is short (G1)
  Since the average processing time of single wafer is short, the moves of this kind of equipment will increase as lot downsizing. Obviously, the waiting time will decrease as lot downsizing. The results are showed as Figure 6.

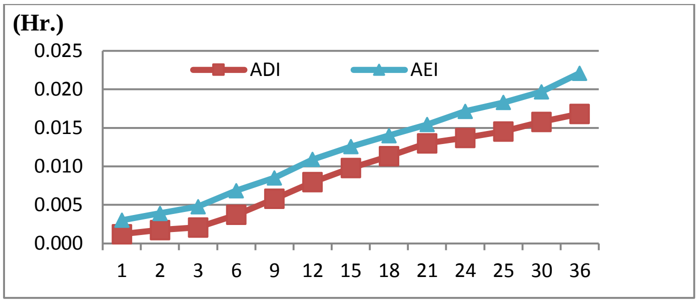

Figure 6. The relationship between lot size and waiting time of M2-G1

- Upstream equipment belongs to M2 and the average processing time of single wafer is long (G2)
  Based on Figure 7 and 8, they revealed that the trend of waiting time is a little fluctuant and not same as the trend of G1equipment which is increasing linearly as lot upsizing. Moreover, the fluctuation of the waiting time trend will be increased when the arrival rate is low, such as implanter equipment.

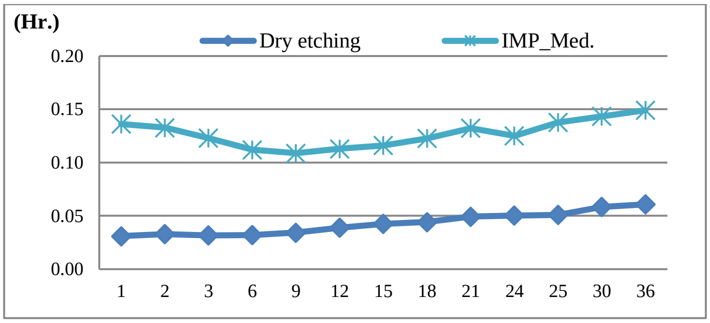

Fig. 7. The relationship between lot size and waiting time of G2

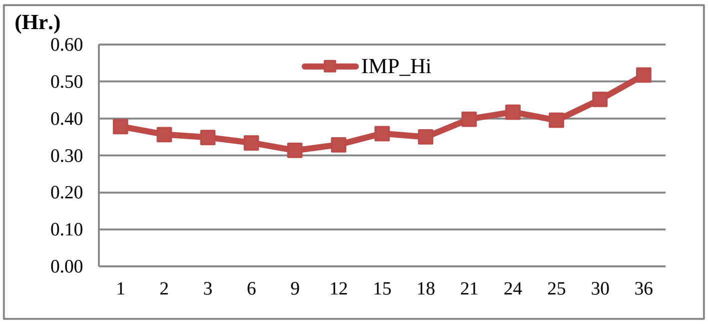

Fig. 8. The relationship between lot size and waiting time of G2

- Upstream equipment belongs to batching process equipment (G3)
  The WIP should be un-batch when upstream equipment is batching process. Therefore, the number of lots will increase as lot downsizing and the waiting time is increased as well. The experiment results are showed as Figure 9.

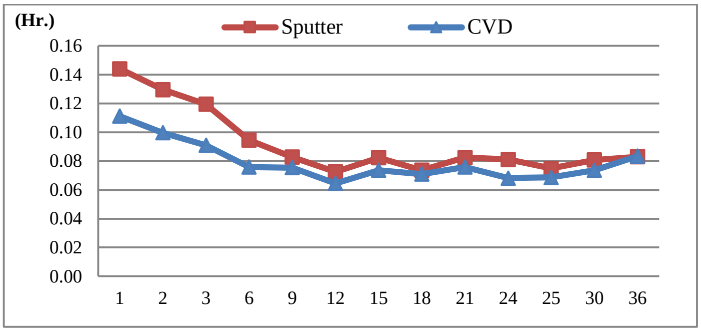

Fig. 9. The relationship between lot size and waiting time of G3

4.3.2.3. Equipment which needs setup (M3)

Regarding to the M3 equipment, the waiting time is increased as lot downsizing and the results are showed as Figure 10. The reason of waiting time increasing is the setup times increased as lot downsizing.

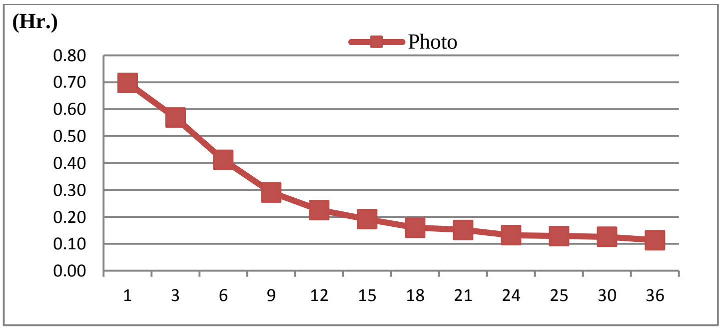

Fig. 10. The relationship between lot size and waiting time of M3

5. Conclusions

Generally, lot size policy is an overall planning issue. Based on the experiment results of this study, they revealed that the best lot size for various performance indices is different. Furthermore, the best lot size for different types of equipment is also different. That is to say, there is no any lot size can let all performances optimized. The research of lot size policy, hence, will be a compromise between all concerned performances. Besides, the batch size of batching process equipment is a critical factor for lot size policy. Because both taking apart and merging actions are avoided, they will get good performances if the batch size is a multiple of lot size. Regarding to the future work, the auxiliary tools, such as the capacity design of AMHS (Automatic Material Handling System) and the planning of stocker, etc. should be considered.

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